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An Electromagnetic Interference Study of Potential Transmitter Sites for the HF Active Auroral Research Program (HAARP)

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13. ABSTRACT *(Maximum 200 words)*

This report presents the results of Electromagnetic Interference (EMI) measurements conducted by the Naval Research Laboratory in June of 1991. This study examined a number of potential sites for the location of the proposedd High Frequency Active Auroral Research Program (HAARP) transmitter facility. The proposed HAARP facility will consist of a large planar array of antennas excited by phased high power transmitters operating in the lower portion of the HF band (2.8 to 8 MHz). Several candidate locations were identified for study in the vicinity of Fairbanks, Alaska. The magnitude of EMI in the population centers and on other commercial and public facilities in the vicinity of Fairbanks from the high power transmitter is a major factor in the site selection process for HAARP. The EMI investigations were conducted in two phases. For Phase I of the study, EMI measurements were conducted at two receiver locations using an airborne transmitter at thirteen potential HAARP sites. The results from the Phase I measurements were examined and the two most promising candidate transmitter locations were selected for more comprehensive measurements during Phase II. For Phase II, comprehensive EMI measurements were made for each of the two candidate transmitter sites. Field strengths were measured at a variety of receiver locations that are representative of the impact area for the EMI from HAARP. The results for both the Phase I and Phase II measurements are presented in this report.

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EXECUTIVE SUMMARY

The High Frequency Active Auroral Research Program (HAARP) is a Congressionally mandated program jointly administered by the Office of Naval Research (ONR) and the Phillips Laboratory (PL), Department of The Air Force. Under the HAARP program, a high power Radio Frequency (RF) transmitting facility will be constructed to permit long term scientific studies of the Earth's ionosphere under all conditions of geomagnetic activity. HAARP will be an advanced, improved RF heater that will radiate significantly high power (on the order of 95 dBW, ~3000 MW), employ spatial agility for heater beam pointing and incorporate state-of-the-art diagnostic tools to study the effects of high power ionospheric heating.

The measurements described in this report were conducted at a number of candidate HAARP transmitter sites in the vicinity of Fairbanks, Alaska. This geographic area is situated within a relatively narrow range of geomagnetic latitudes that provide nearly continuous availability of ionospheric processes and phenomena required to address the HAARP research objectives. From preliminary design considerations, ONR determined that an area of 400 acres was required for the transmitter antenna array. ONR and PL consulted with the Geophysical Institute (GI) of the University of Alaska, Fairbanks, Alaska to define preliminary design criteria and to select potential transmitter locations. Roen Design Associates identified 17 potential HAARP transmitter sites in the vicinity of Fairbanks, AK that satisfied a majority of the preliminary design criteria.

In order to determine the degree of potential interference from the proposed HAARP facility, NRL conducted a series of field strength measurements in June 1991 to guide the transmitter site selection process. These measurements were performed in two phases. Phase I was a survey of each of the potential transmitter sites utilizing two receiver locations that were representative of the major EMI impact areas. The two most promising transmitter locations from the Phase I results were selected for more comprehensive measurements during Phase II. Phase II EMI measurements were then conducted at the two candidate transmitter sites. Field strengths were measured at a wider variety of receiver locations that provided a more comprehensive representation of the EMI impact area from HAARP.

The Phase I field strength amplitudes were compared to free space, plane wave propagation conditions. Analysis showed that the measured signal attenuation was greater than that expected for typical free space conditions (often exceeding it by greater than 50 dB) . The reduced signal amplitude (additional propagation path loss) is the result of propagation near and along the Earth's surface and, in some cases, to the physical blockage to line-of-sight conditions caused by intervening hills. In general, the dominant propagation mode for the rugged topography of the region is scattering and not the easily calculable plane wave propagation typical of free space conditions. This increased path loss was observed for almost all of the candidate HAARP locations surveyed in the Phase I and II measurements.

The "quick look" analysis of the Phase I data showed that the candidate transmitter locations likely to exhibit the least overall EMI impact were the sites identified in the Roen study as #17 and #12. There were other candidate sites with slightly lower EMI but other considerations, such as an active mining operation in direct line-of-sight, precluded further examination of those locations. In order to examine the EMI impact from site #17 and #12, a temporary transmitter was installed, successively, at each of these locations. Received signal amplitudes were measured at seven locations representing either major population centers, DOD installations, or commercial and public facilities in the vicinity of Fairbanks. The Phase II field strengths demonstrated that the path loss to distant sites exceeded spherical Earth propagation theory. Measurements using directive antennas showed that direction of arrival could not be established in the majority of cases, and that the received signal was dominated by scattering modes.

The potential EMI impact from a HAARP transmitter would be to produce interference to the TV video signal. The measured field strengths for the Phase I data showed that approximately 35% of the candidate transmitter locations would produce TV video interference at the two receiver locations. The Phase II data showed that TV video interference would be produced at about half of the sampled receiver locations for both the site #17 and #12 candidate HAARP transmitter locations. In particular, the site #17 transmitter would produce severe TV video interference in the Cleary Summit area. Distortion would also be produced at the Lone Creek subdivision, the Poker Flat Research Range and at Ft. Wainwright. The Site #12 transmitter location would produce interference in the Haystack subdivision and at Eielson Air

Force Base.

The data obtained in this study was applied to determination of interference to the commercial television service only. Results can also be applied to other services to determine the EMI susceptibility of other communication applications. However, we believe the results presented here for interference to television usage are representative of the overall EMI potential of the sites studied.

AN ELECTROMAGNETIC INTERFERENCE STUDY OF POTENTIAL TRANSMITTER SITES FOR THE HF ACTIVE AURORAL RESEARCH PROGRAM (HAARP)

I. INTRODUCTION

The High Frequency Active Auroral Research Program (HAARP) is a Congressionally-mandated program, jointly administered by the Office of Naval Research (ONR) and the Phillips Laboratory (PL), Department of The Air Force. Under the HAARP program, a high power radio frequency (RF) transmitting facility will be constructed in Alaska to permit long term scientific studies of the Earth's ionosphere under all conditions of geomagnetic activity. The HAARP facility will provide sufficient energy densities in the ionosphere to facilitate investigations of such diverse areas of research as:

- The generation of Extremely Low and Very Low Frequency (ELF and VLF) waves in the auroral region for special communication applications.

- The acceleration of electrons to produce optical and infra-red (IR) emissions.

- The production of field aligned irregularities of sufficient electron density to scatter radio waves.

- Other phenomena triggered by very high power RF heating of the ionosphere.

The measurements described in this report were conducted at a number of HAARP transmitter candidate sites in the vicinity of Fairbanks, Alaska. This geographic area is situated within a relatively narrow range of geomagnetic latitudes that provide nearly continuous availability of ionospheric processes and phenomena required to address the stated research objectives. The Fairbanks area affords the opportunity to take advantage of research activity at the Poker Flat Research Range (PFRR) and to use in-situ rocket measurements of the heated ionospheric region. Current ionospheric research efforts employ the High Power Auroral Stimulation (HIPAS) RF heating facility [1], located in the Chena River valley area near Fairbanks. HAARP will be an advanced, improved RF heater in comparison to HIPAS, that will radiate significantly higher power (on the order of 95 dBW, ~3000 MW), employ spatial agility for heater beam pointing and incorporate state-of-the-art diagnostic tools to study the effects of high power ionospheric heating.

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The HAARP transmitting facility will be carefully designed and constructed to minimize the electromagnetic effect on the surrounding area. The HAARP transmitting antenna array will produce maximum radiation at high elevation angles with significantly low sidelobe radiation in the horizontal direction. However, all antenna array systems have residual radiation or sidelobes at off-boresite directions and it is these sidelobes that are responsible for interference to other users of the electromagnetic spectrum. Since HAARP will use extremely high transmitting power to excite the ionosphere, the concern for electromagnetic interference (EMI) caused by residual radiation in the sidelobes is a prime factor in the selection of a facility location.

To determine the potential EMI from the HAARP transmitter at a particular location, calculations must be performed in much the same manner that link analysis is conducted for communications channels. Parameters that must be determined or estimated include the radiated power, the transmitting antenna gain and the propagation path loss to the potential site of the interference. The topography between most of the candidate HAARP transmitter sites and the population centers and other commercial and public facilities in the vicinity of Fairbanks is rough and hilly. The propagation characteristics for the rugged, hilly terrain were anticipated to provide conditions that are dominated by scattering and not by line-of-sight or conventional curved Earth propagation. Consequently, the calculated path loss associated with simple spreading of the transmitted wave can only be used for rough order-of-magnitude estimates. Measurements are required to establish actual path losses between each the candidate transmitter sites and a particular receiver location.

From preliminary design considerations, ONR determined that an area of 400 acres was required for the transmitter antenna array. ONR and PL consulted with the Geophysical Institute (GI) of the University of Alaska, Fairbanks, Alaska for preliminary identification of potential transmitter locations. A preliminary set of criteria was developed by ONR, PL and GI. Roen Design Associates was hired by GI to study the guidelines and identify candidate sites from topographical maps and land records [2]. The preliminary design criteria were:

1. Candidate locations must be within a 33 mile radius of the Poker Flat Research Range.

2. Site must be 400 acres with a length to width aspect ratio of 2:1 or less.
3. Site must be a planar surface with a slope ≤ 11 degrees and maximum elevation deviation from the plane must be $\pm$ 6.1 meters ($\pm$20 feet).
4. Distance to the nearest road used by the general public or to man made structures must be greater one-half mile.
5. Federal and state lands were of highest priority, but the Roen study did not exclude a potential site if the land was privately owned.
6. Horizon angles from the site to Fairbanks and to Eielson Air Force Base were specified. The horizon angle specified was a minimum of 1 degree and a maximum of 4 degrees, depending upon distance between the site and Fairbanks/Eielson. (Higher angles were defined for shorter distances.)
7. Direct line-of-site to substantial human population was not permitted.
8. Practical access using an existing State maintained road was a requirement. Construction of an access road of not more than 10 miles was also a requirement
9. Soil conditions were not considered.
10. The site could not be located in an active flood plain.

In addition to item 5 in the above criteria, considerable cost savings could be derived from publicly owned land. The cost for privately owned land might escalate the cost beyond reasonable limits.

The Roen study identified 17 potential HAARP transmitter sites that satisfied a majority of the preliminary design criteria. A map identifying the 17 sites is shown in Fig. 1. In an attempt to identify the EMI impact for each of the 17 potential transmitter locations, the Roen study analyzed the contour profiles using topographical maps. While

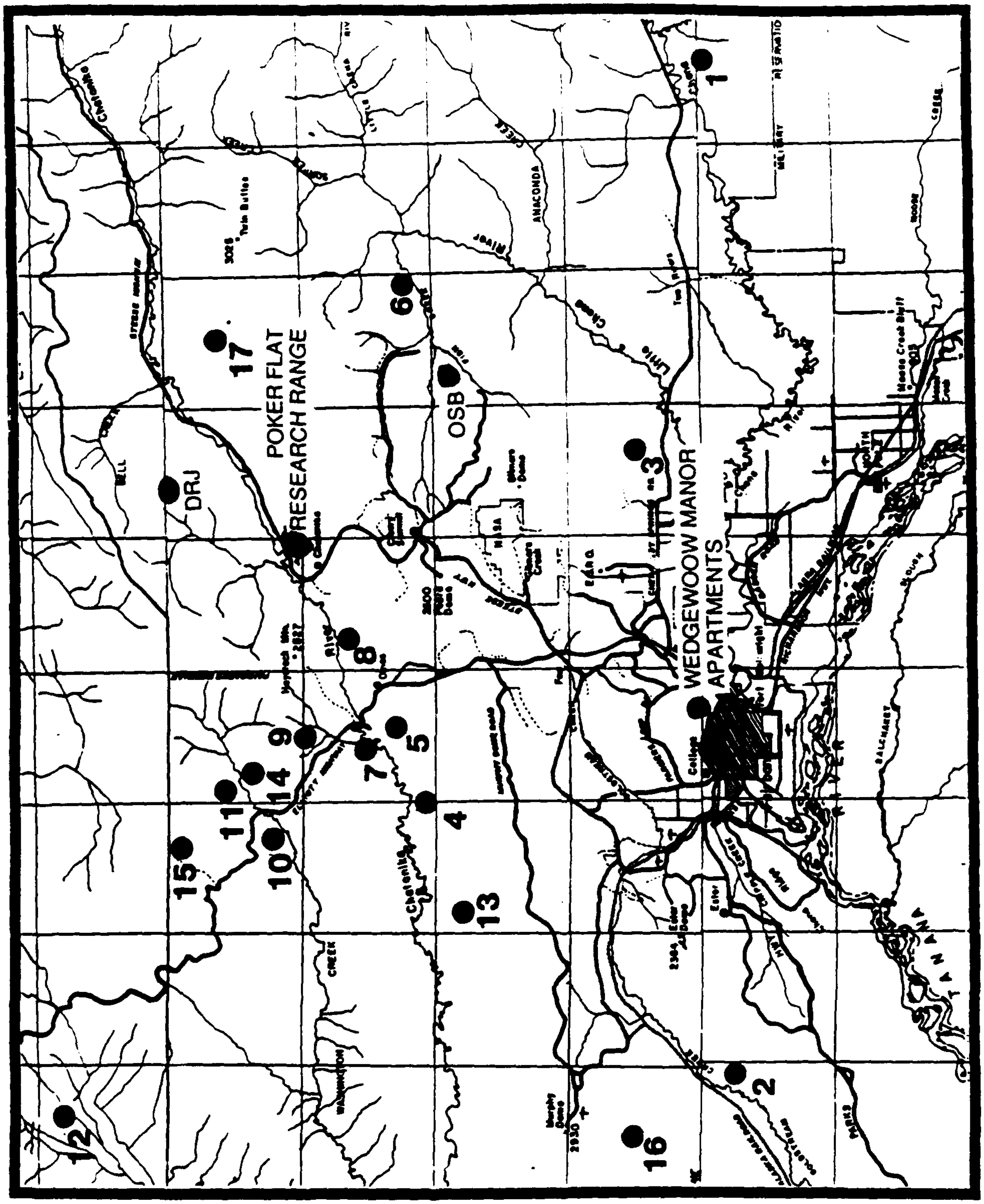

Figure 1. Seventeen potential HAARP transmitter locations identified by examination of topographical maps for the area and the criteria specified by the Geophysical Institute of the University of Alaska.

map profiles are an aid to identifying the potential for EMI, the rugged, hilly terrain of the area north of Fairbanks dictates that actual measurements of field strengths are necessary for a more accurate indication of EMI effects on the population centers and other commercial and public facilities in the vicinity of Fairbanks.

NRL conducted a series of field strength measurements in June 1991 to determine the risk of EMI from each potential transmitter site, to guide in the selection process. These measurements were performed in two phases. Phase I was a survey of each transmitter site utilizing two receiver locations that are representative of the major EMI impact areas. The results from the Phase I measurements were examined and the two most promising candidate transmitter locations were selected for more comprehensive measurements. Phase II EMI measurements were then conducted using these two candidate transmitter sites. Field strengths were measured at a larger number of receiver locations during Phase II, which provided a more comprehensive representation of the EMI impact area from a HAARP facility.

The following sections of this report describe the actual techniques employed to collect the data, analysis, presentation of the results of the data analysis and conclusions.

II. Measurement Technique

A. Phase I Measurement Technique

The Phase I measurements were designed to survey the EMI from many potential HAARP transmitter locations. The approach selected by NRL was to construct a simple transportable transmitting system that could be easily moved to different sites and to measure received signal levels at critical locations. Examination of the received signal amplitude could then be used to assess potential for the EMI from each of the candidate transmitter sites and guide the selection for the Phase II portion of the study. The Roen report [2] identified a total of 17 candidate transmitter locations, as shown in Fig. 1. Eleven of the "Roen" sites (4, 5, 6, 9, 10, 11, 12, 14A, 14C, 15 and 17) and two additional locations that were identified through discussions at ONR and GI were selected for inclusion in the Phase I effort. The two additional sites are designated "OSB" and "DRJ" in Fig. 1. Two receiver locations were

selected for the Phase I survey measurements and their locations are indicated in Fig. 1. Poker Flats was chosen as a primary receiver location due to the number of potential transmitter sites identified in the Roen report in close proximity to the research range. The second receiver site represented the population center of the Fairbanks area and was located at the Wedgewood Manor Apartments, on the northeast side of the city.

Since the planar antenna array to be used at the HAARP facility will be a horizontally polarized radiator, the transmitting and receiving antennas for the Phase I EMI measurement were horizontally polarized. The challenge for this study was how to sample 13 transmitter locations in rough, undeveloped terrain, and measure the signal amplitude at 2 receiver sites in an efficient manner. The technique chosen was to make the transmitter an airborne system, allowing the survey of the 13 potential transmitter locations in a relatively short time.

A relatively slow speed airborne system was required in order to collect several samples of the received signal amplitude for each transmitter frequency at each transmitter location. A helicopter was selected to satisfy these criteria. An airborne dipole antenna was assembled using a 9.8 meter length of aluminum tubing. This dipole was suspended approximately 15.3 meters below the helicopter, which was flown to keep the height of the dipole antenna between approximately 21 and 30.5 meters above the ground during the field strength measurements. EMI data collected in this fashion are believed to be representative of a full scale HAARP installation at the candidate transmitter locations due to the similarity in polarization and height above the ground.

A block diagram for the transmitting system is shown in Fig. 2. A Kenwood TS-440 HF transceiver, operating in the continuous wave (CW) mode, generated the transmitted RF test signal. Since the antenna was electrically short in the frequency range studied, a tuning network was employed for efficient power transfer from the transceiver to the antenna. A variable tapped inductor tuning network was used for matching the antenna's capacitive reactance. The inductor tap selection for a given frequency was controlled by an operator aboard the helicopter. The TS-440, power monitor and the switch control were located in the helicopter. The tuning network and antenna were suspended approximately 15.3 meters below the helicopter. In addition to the tuning network, the automatic tuning feature of the TS-440 was

employed to obtain the best power transfer from the transceiver to the antenna. The transmitter was operated at a maximum output power of 100 watts. The RF Wattmeter measured the power delivered to and reflected by the antenna system, from which the radiated power could be determined.

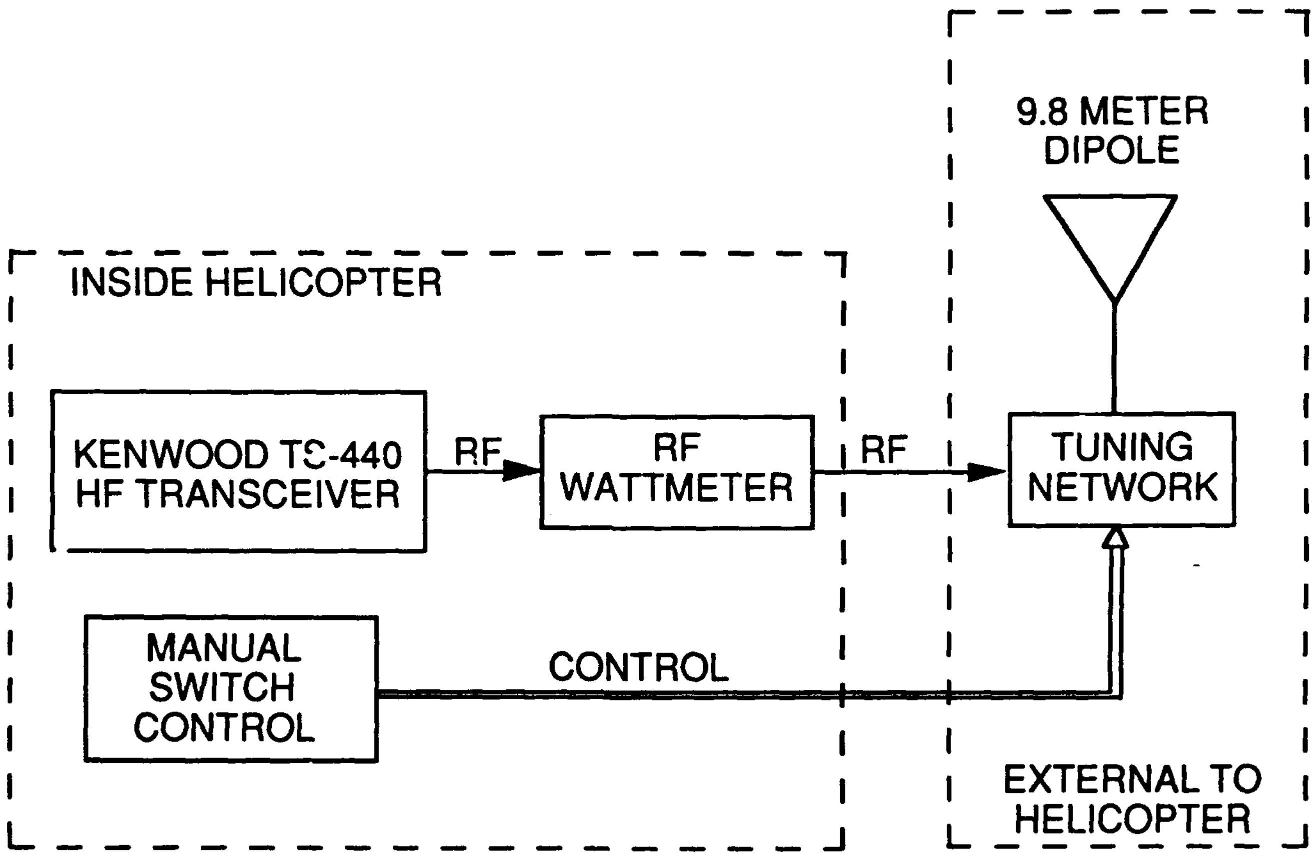

Figure 2. Phase I Airborne Transmitting System.

The receiving system block diagram is shown in Fig. 3. The receiving antenna was a horizontal wire dipole constructed to be resonant at 5.42 MHz and was installed at a height of approximately 6.1 meters above the ground using plastic PVC pipe. Since the measurements were intended to be survey type measurements, no ground screen was incorporated in the antenna installation. The antenna was connected to a Hewlett Packard (HP) Selective Level Measurement Set (SLMS). The SLMS was chosen because of the ease with which it could be computer controlled and make repetitive measurements. The SLMS was controlled by a HP PC-308 Vectra Computer which also

performed the data collection function of the received signal levels. The data were stored on disk for post-measurement analysis.

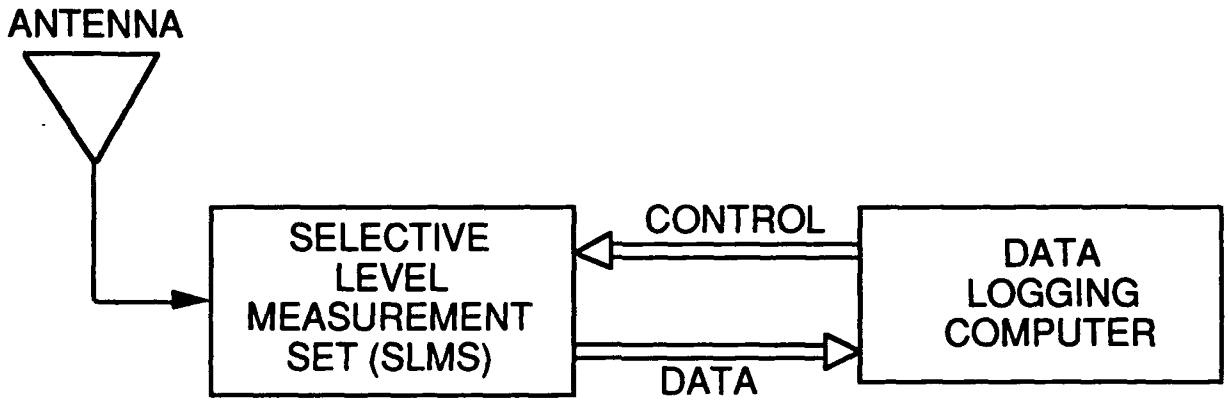

Figure 3. Phase I Receiver System.

The four frequencies used for the Phase I survey measurements were 3.835 MHz, 5.420 MHz, 6.440 MHz, and 7.360 MHz. Measurements at all four frequencies at a particular transmitter location were completed, then the helicopter flew to the next potential transmitter site. Measurement coordination was achieved using VHF/UHF radios. After completing the measurements for all 13 transmitter locations at the Poker Flats on 4 June, the receiver was moved to the Wedgewood Manor Apartments (WMA) and the measurement process was repeated on 5 June.

B. Phase II Measurement Technique

After a preliminary analysis of the data, the two primary candidate HAARP transmitter locations were identified as Site numbers 17 and 12 (reference numbers in the Roen report [2]). The measurements to quantify the EMI from these two sites were performed by the temporary installation of a representative HAARP transmitter. A temporary receiver was installed at seven locations that represented a sampling of the population centers and other commercial and public facilities in the vicinity of Fairbanks. Since the HAARP facility will be a horizontally polarized radiator, the temporary transmitting and receiving antennas installed for the Phase II EMI measurement were horizontally polarized.

In order to span the HAARP frequency band of 2.8 to 8 MHz, a multi-element transmitting antenna was fabricated, consisting of two sets of three center-fed resonant dipoles. This type of antenna was chosen because characteristics of resonant dipoles are well known [3]. The data analysis therefore would not be complicated by uncertainties due to the feed point impedance and pattern of the antenna. A non-resonant antenna system (such as was used in Phase I) would require knowledge of antenna impedances for both the transmitting and receiving systems in order to accurately compensate for these effects.

The resonant antenna systems used in Phase II avoided the need for corrections associated with a poor antenna feed point impedance. Each dipole was constructed to be resonant at a particular frequency in the HAARP band. A dielectric spacer was fastened to the ends of these dipoles and an electrical jumper connection, as is shown in Fig. 4, was provided to increase the dipole length. The longer dipoles resonated at the lower frequencies in the HAARP band. This jumper configuration provided a quick, efficient mechanism to convert the antenna system from being resonant at three higher frequencies to be resonant at three lower frequencies. Thus, six HAARP frequencies could be measured in a relatively short time frame. The antenna system was connected to the transmitter by a balun. Crank-up towers elevated the antenna system to a representative HAARP system height of approximately 20 meters. A duplicate antenna system was installed in an orthogonal orientation, at the same height. The second antenna set was incorporated into the measurements to provide radiation in all directions due to the complementary antenna patterns from the two orthogonal antenna systems and as a possible aid to enable a determination of the skywave contribution of the received signal.

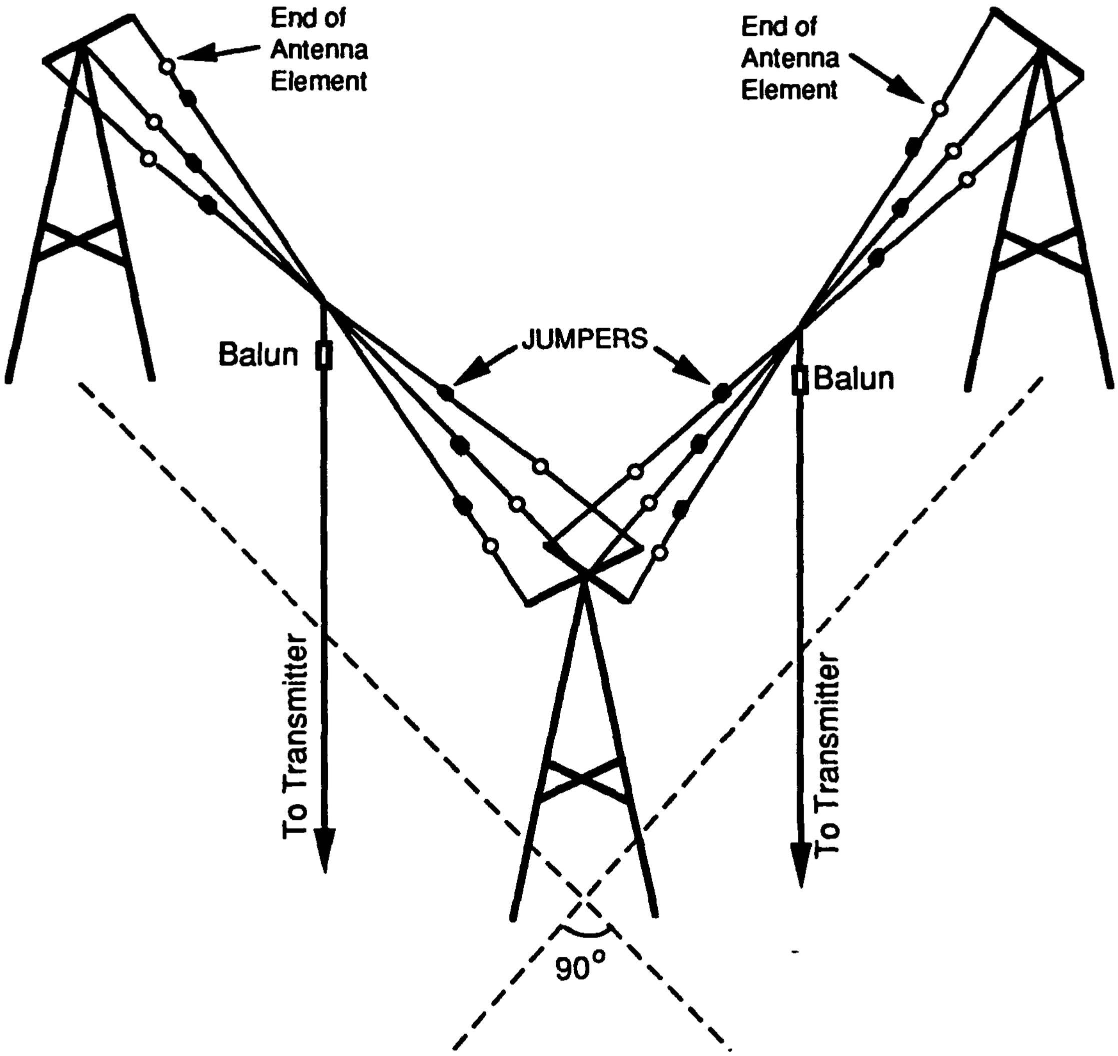

Figure 4. Phase II Transmitting Antenna System.

The transmitting dipole antenna system was designed to be resonant at a specific set of test frequencies. The resonance of any multi-wire structure is affected by mutual coupling between the wire elements. To insure that mutual coupling effects were taken into account, each antenna system was raised to operating height and a network analyzer was used to determined the exact resonant frequency of each dipole. The individual dipole lengths were adjusted to produce the resonant condition at the following six frequencies: 2.84 MHz, 3.72 MHz, 4.49 MHz, 5.69 MHz, 6.76 MHz, and 7.83 MHz.

Much more complicated was the construction of the second,

orthogonal antenna set that must resonate at the same frequencies as the first antenna system. The wire element lengths of the second antenna system required several iterations to obtain resonance at the same frequency for both antennas.

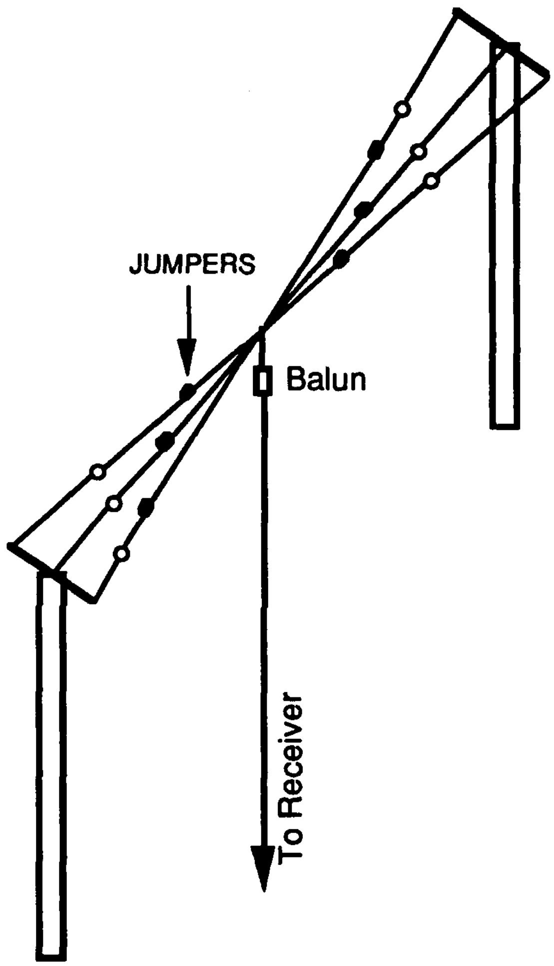

Figure 5. Phase II Receiving Antenna System.

The antenna system for the receiver, Figure 5, was fabricated using the same multi-wire technique as was used for the Phase II transmitting antenna. As in Phase I, the receiving antenna was installed at a height of 6.1 meters above the ground using plastic PVC pipe. A similar iterative tuning process was employed to adjust the dipole elements to one of the frequencies listed above. A radial ground screen of eight lengths of #14 wire, each 50 ft. long, was laid out beneath the receiving dipole, centered on the feed point of the dipole.

The Phase II transmitter system block diagram is shown in Fig. 6. The Kenwood Model TS-440 HF transceiver was used to provide a 100 watt CW test signal to each of the orthogonal dipole antennas. The amplified CW signal was connected to the balun of each antenna system through the power monitor. Since the antenna systems employed a resonant dipole at each measurement frequency, a tuning network at the antenna feed point was not necessary. The automatic tuning feature of the TS-440, however, was used to insure the best power transfer to the antenna system. The power monitor was used to measure the forward and reflected power so that the radiated power could be determined.

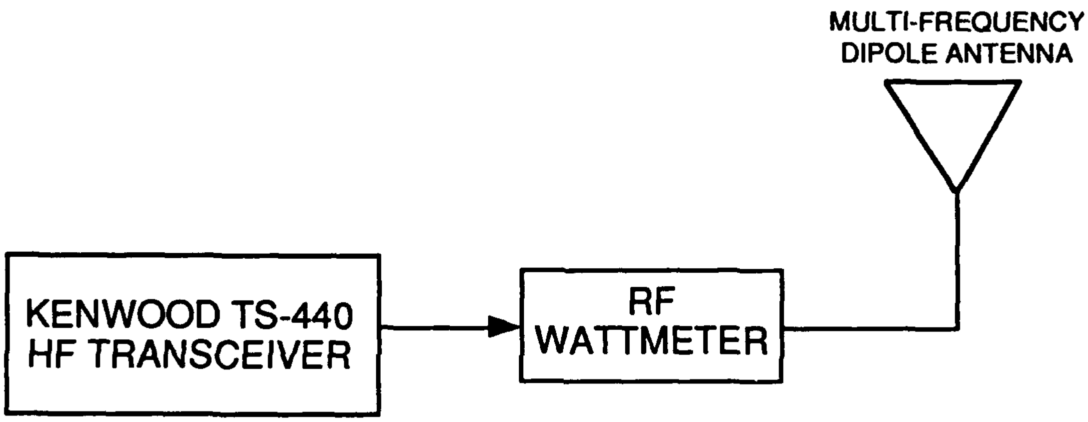

Figure 6. Phase II Transmitter System.

The receiving system block diagram shown in Fig. 7 is the same as that used in Phase I, except for the addition of two low noise amplifiers. The amplifiers provided a composite gain of 27 dB and a system noise figure of 5 dB. The amplifiers were incorporated to insure that any received signal amplitude was greater than the internal noise level of the SLMS. (The noise figure for the Phase I measurements is about 20 dB, which is the noise figure of the SLMS. This was considered adequate for Phase I, which was a survey-type measurement). The data logging computer (HP PC-308 Vectra Computer) controlled the SLMS and recorded the measured data on disk for post-measurement analysis.

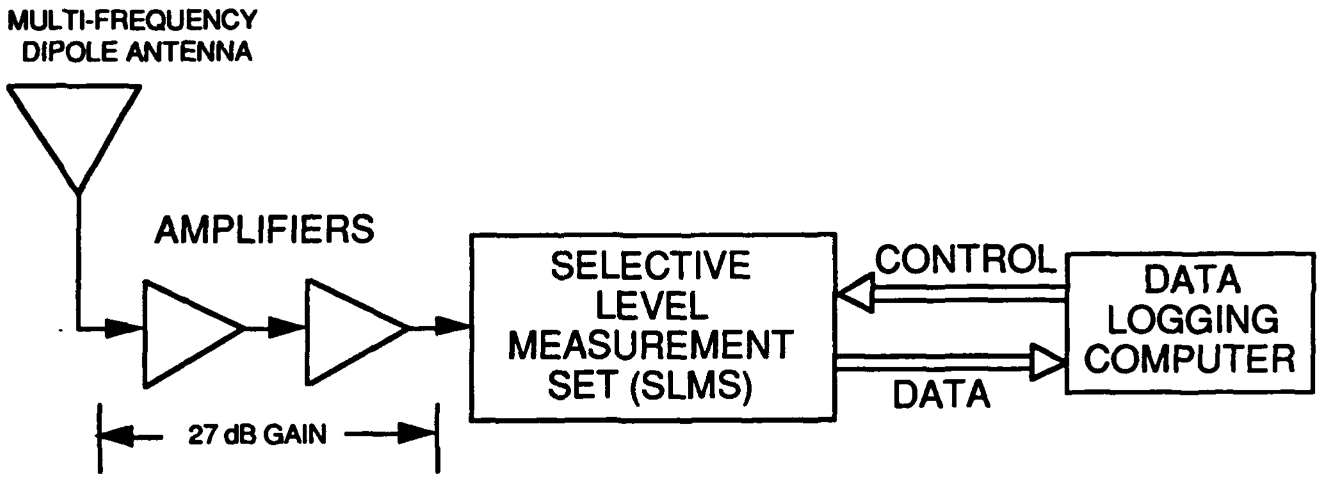

Figure 7. Phase II Receiving System.

As with Phase I, VHF/UHF, voice radio communications between the sites were employed to coordinate the operations. The Phase II operations began with erecting the temporary transmitting system at the selected location. The temporary receiving system was transported to the first designated site and assembled. After the data was recorded on the data logging computer's hard disk for each frequency and for each of the orthogonal transmitting dipole antennas, the receiving system was disassembled and transported to the next location. The data collection for the transmitter at Site #17 was accomplished on 11, 12 and 13 June 1991. Data collection for the transmitter at Site # 12 took place on 16 and 17 June 1991.

III. Data Analysis and Discussion

The data analysis for both the Phase I and II measurements involved transforming the received signal amplitudes into propagation path loss and field strength values. Development of path loss values from the signal level data requires knowledge of the antenna gains for both the transmitting and receiving antennas. The propagation path loss between the transmitting and the receiving locations required determination of antenna gains at low elevation angles. For Phase I antenna gain characteristics, the Numerical Electrical Code (NEC) [4] was used to obtain the appropriate antenna gains. Since both the transmitting and receiving antennas for Phase II were resonant at the measurement frequencies, standard antenna pattern calculations [5] were used for the antenna gain calculations for the Phase II antennas.

A. Phase I - Calculations

The actual transmitter radiated power (P_t), in dB, is determined from :

$$P_t = P_{tuner} + G_t + L_{tuner} \qquad 1$$

where:

- P_t is the radiated power in dBW.
- G_t is the gain of the transmitting antenna in the direction of the receiver (in dB).
- L_{tuner} is the loss associated with the tuning network (in dB).

P_{tuner} is the power delivered to the matching network based on forward and reflected power measurements at the transmitter and calculated from transmission line equations. The transmitting antenna gain was obtained from NEC analysis [4].

The available power at the feed point of the receiving antenna (P_r), in dB, is determined from :

$$P_r = P_{slms} + L_{cable} + L_{mis} - G_r \qquad 2$$

where:

- P_{slms} is the received signal amplitude measured by the SLMS (in dBW).
- L_{cable} is the transmission line loss in the cable connecting the SLMS to the antenna (in dB).
- L_{mis} is the impedance mismatch loss between the antenna and a 50 Ω system (in dB).
- G_r is the gain of the dipole receiving antenna in the direction of the transmitter (in dB).

Using above factors, the path loss (L_{path}) is determined from :

$$L_{path} = P_t - P_r \qquad 3$$

The actual *free space* spreading loss (L_{FS}) for plane wave propagation is calculated using the Friis Transmission Formula [6] :

$$L_{FS} = 20 \log \left[\frac{\lambda}{4 \pi d} \right] \qquad 4$$

where:

λ is the wave length, ($\lambda = \frac{300}{F_{MHz}}$), where F_{MHz} is the frequency in MHz.

d is the distance between the transmitting and receiving sites.

In addition to the path loss calculations, the received energy for the Phase I measurements was converted to field strength amplitudes. The power radiated by the transmitting system is required in determining field strength levels. For the Phase I measurements the transmitter power was based upon a 100 watt (20 dBW) transmitting system. The transmitter power, (P_{tpa}), in dB, scaled to the 20 dBW level is determined from a modified form of (1):

$$P_{tpa} = 20 - P_{tuner} - G_t - L_{tuner} \qquad 5$$

where the parameters have been defined previously. The transmitting antenna gain is added in (1) to obtain the actual radiated power, but is subtracted in (5) as part of the normalization to a 100 watt radiated power level.

The power available (P_r), in dB, at the feed point of the receiving antenna is a modified form of (2) :

$$P_r = P_{slms} + L_{mis} - G_r + P_{tpa} \qquad 6$$

where P_{tpa} is calculated from (5)

The receiving antenna gain (G_r) was calculated using [5] :

$$G_r = 20 \log \left\{ \frac{\cos\left[\left(\frac{\pi}{2}\right)\cos(\theta_r)\right]}{\sin(\theta_r)} \right\} \qquad 7$$

where:

θ_r is the angle measured from a line along the receiving dipole to the transmitter location.

The L_{mis} was determined from network analyzer measurements accumulated after the fabrication and tuning of the receiving antenna was completed. The P_r was converted to equivalent field strength, E and scaled to be relative to 1 μVolt/meter, using:

$$E = \left[\left(\frac{2\pi}{\lambda}\right)\sqrt{(120\ P_r)}\right] * 10^6 \qquad 8$$

The normalization process used in the analysis references the calculated field strengths to an equivalent radiated power (ERP) of 20 dBW (100 watts) and the electric field data is calibrated to 1 μVolt/meter. This allows the results to be scaled to any transmitting and receiving systems. For a given transmitting system, the field strength can be scaled by that system's ERP to obtain actual electric field values at the receiving location.

B. Phase II - Calculations

The data analysis for the Phase II measurements focused on the field strength amplitudes, as was done for the Phase I data. The Phase II transmitter power, (P_{tpa}), in dBW, is obtained from a modified form

of (5) :

$$P_{tpa} = 20 - 10 \log(P_{fwd} - P_{ref}) - G_t + L_{TL} \qquad 9$$

In this equation, P_{tpa} is normalized to a 100 watt transmitting system. The transmitting antenna system was a set of resonant dipoles and so tuning network was employed. For a resonant antenna system, the measured forward and reflected power levels are equal to the amplitudes at the antenna feed point, and the line measurements are independent of the placement of the power meter. In this case, the measured Voltage Standing Wave Ratios were low enough to make the simplifying assumption in (9) that the power delivered to the transmitting antenna is simply the forward minus the reflected power. For the Phase I analysis, the cable loss, L_{TR},, was a factor in determining the forward and reflected antenna feed point power and was used in solving the transmission line equation. For the Phase II analysis, the resonant system allowed L_{TR}, be accounted for as a single additive parameter. The resonant antenna gain can be obtained from [5] using :

$$G_t = 20 \log \left\{ \frac{\cos\left[\left(\frac{\pi}{2}\right)\cos(\theta_t)\right]}{\sin(\theta_t)} \right\} \qquad 10$$

where:

θ_t is the angle measured from a line along the transmitting dipole to the receiver location

The received power, P_r, is obtained from a modified form of equation 6:

$$P_r = G_a + P_{slms} + L_{mis} - G_r + P_{tpa} \qquad 11$$

where G_a is the gain of the low noise amplifiers inserted in the signal path between the antenna and the SLMS, in dB (see Fig. 7), and the other parameters are the same as those defined for the Phase I calculations.

G_r was calculated using (7), and the result was used in equation 11 to calculate P_r. The equivalent field strength, E, was then determined using (8).

C. Phase I - Results

The receiver locations for the Phase I data at the Poker Flat Research Range (PFRR, or just Poker Flats) and the Wedgewood Manor Apartments (WMA) and the transmitter sites are indicated in Fig. 1. Due to the topography of the region, the propagation path between the transmitter and either of the the receiving sites was obstructed for all sites evaluated. Topographical maps for the region were examined to obtain the elevation angle between the transmitting location and the peak of the closest topographical obstruction. The transmitting antenna gain for that elevation angle was used in the analysis to obtain the measured path losses. The same process was used to obtain the correct elevation angle and antenna gain for the receiving site. Calculated values for L_{path}, the path loss, along with L_{FS}, the free space spreading loss for plane wave propagation, are presented in Tables 1 and 2. Table 1 shows the results for the receiver at Poker Flats and Table 2 shows the results for the receiver at WMA. The right hand column in these tables is the additional measured loss above the free space spreading loss. The measured loss is greater than the free space loss for almost all transmitter sites and frequencies. This additional loss is as much as 53 dB greater than the free space loss (Table 1 , Transmit Site #6, 7.360 MHz). The rugged topography of the region implies that the dominant propagation mode for most of the sites investigated is scattering from the multiple peaks and ridges in the area. (A numerical analysis of scattering mode propagation for comparison with measurements, over each of the paths investigated was not attempted in this study.) The few cases where the calculated spreading loss is higher than the measured loss are attributed to constructive scattering or to a multipath geometry.

The Phase I field strength data, E, is presented in graphical form in Fig. 8 for the case of the receiver at PFRR and in Fig. 9 for the receiver at

WMA. The data has been scaled to reflect the field strength that would be produced by a full scale HAARP transmitter antenna array operating at full power. The HAARP transmitter specification requires a peak radiated power in the zenith direction of 95 dBW. Any EMI will come from sidelobe radiation of the HAARP antenna system and the current HAARP specification for the sidelobes is 20 dB down from the peak. Since the data collected for this report was based upon a transmitter power of 20 dBW, the calculated E values using equation have been adjusted upward by 55 dB (~316 kW) for both Fig 8 and 9. If the propagation modes were dominated by plane wave conditions, the curves in Fig. 8 and 9 would be straight lines that monotonically decreased with increasing frequency. From the free space path loss, the plane wave E values would decrease by 5.7 dB from 3.835 to 7.36 MHz. The actual measured data does show some general tendency to be decreasing with increasing frequency, but also displays deviations as large as 19.3 dB decrease between 3.835 and 5.42 MHz for radiation between Site #4 and Poker Flats. The data for the receiver at WMA displays similar deviations from linearity, but the departure is somewhat less than the Poker Flats data.

It is also possible that skywave propagation had been received and dominated the Phase I measurements. In order to estimate the skywave contribution to the signal amplitude, Digisonde data was examined. A Digisonde is an HF sounder that measures the state of the ionosphere and provides information about the frequencies that are propagating for vertical incidence. The Air Force Phillips Laboratory operates a Digisonde just outside Fairbanks at College, Alaska. The skywave path for all of the Phase I and Phase II measurements would require antenna take-off angles that are categorized as near-vertical-incidence. Therefore, the College Digisonde data was examined [8] to determine which frequencies were propagating during the measurements. The College Digisonde data established that as the result of a severe magnetic storm during the Phase I data collection, with the receiver at WMA, near-vertical-incidence propagation was not possible for any frequency in the HAARP band. The deviation from monotonically decreasing linearity is similar for the data presented in Fig. 8 for Poker Flats and in Fig. 9 for the WMA data. The College Digisonde data shows a more normal ionosphere for the time when the data was collected at PFRR. It is believed unlikely that skywave contamination is the cause of the non-linear plots in Figs. 8 and 9 , but that it is the result of scattering and multipath effects produced in the rugged measurement environment.

TABLE 1 PHASE I MEASUREMENTS RECEIVER AT POKER FLAT SPACE WAVE ANTENNA GAIN CALCULATIONS						
TRANSMIT SITE	FREQ (MHz)	TX ANT GAIN (dBi)	RX ANT GAIN (dBi)	MEASURED PATH LOSS (dB)	CALCULATED FREE SPACE SPREADING LOSS (DB)	EXCESS LOSS ABOVE THE FREE SPACE LOSS (dB)
OSB	3.835	-8.60	-11.7	-108.7	-68.6	40.1
	5.420	-4.70	-13.1	-122.3	-71.6	50.7
	6.440	-3.60	-14.4	-116.2	-73.1	43.1
	7.360	-3.20	-15.8	-118.9	-74.3	44.7
6	3.835	-9.00	-11.7	-112.3	-70.5	41.8
	5.420	-5.10	-11.6	-116.8	-73.5	43.2
	6.440	-4.00	-11.9	-115.9	-75.0	40.9
	7.360	-3.60	-12.1	-129.2	-76.2	53.0
17	3.835	-19.00	-23.4	-94.2	-68.0	26.2
	5.420	-15.10	-25.2	-93.5	-71.0	22.5
	6.440	-13.90	-26.6	-96.2	-72.5	23.7
	7.360	-13.50	-28.2	-95.3	-73.6	21.7
DRJ	3.835	-15.00	-15	-73.1	-64.6	8.5
	5.420	-10.90	-15	-93.4	-67.6	25.9
	6.440	-9.80	-15.1	-95.8	-69.1	26.7
	7.360	-9.40	-15.3	-104.2	-70.2	33.9
15	3.835	-35.30	-12.2	-68.6	-71.3	-2.7
	5.420	-31.40	-12.4	-86.4	-74.3	12.1
	6.440	-30.30	-12.8	-83.3	-75.8	7.5
	7.360	-29.80	-13.2	-96.9	-77.0	19.9
10	3.835	-13.90	-16.1	-94.9	-70.5	24.4
	5.420	-9.90	-17.4	-108.3	-73.5	34.8
	6.440	-8.80	-18.5	-113.7	-75.0	38.7
	7.360	-8.40	-19.7	-112.2	-76.2	36.0
11A	3.835	-17.50	-13.2	-94.6	-69.3	25.3
	5.420	-13.60	-13.9	-109.9	-72.3	37.6
	6.440	12.40	-14.5	-101.5	-73.8	27.7
	7.360	-12.00	-15.3	-114.0	-74.9	39.0
14A	3.835	-21.20	-14.3	-88.7	-67.8	20.9
	5.420	-17.30	-15.3	-102.5	-70.8	31.7
	6.440	-16.20	-16.2	-100.9	-72.3	28.6
	7.360	-16.00	-17.2	-102.3	-73.5	28.9
14C	3.835	-12.20	-14	-93.9	-66.3	27.6
	5.420	-8.30	-14.8	-99.4	-69.3	30.1
	6.440	-7.10	-15.7	-105.6	-70.8	34.8
	7.360	-6.70	-16.5	-106.4	-72.0	34.5
9	3.835	-11.50	-16.6	-90.8	-66.5	24.4
	5.420	-7.50	-18.4	-99.9	-69.5	30.5
	6.440	-6.40	-19.8	-102.4	-71.0	31.4
	7.360	-6.00	-21.4	-101.6	-72.1	29.5
4	3.835	-33.50	-26.7	-50.6	-70.4	-19.8
	5.420	-29.60	-28.5	-72.7	-73.4	-0.7
	6.440	-28.50	-29.9	-75.8	-74.9	0.8
	7.360	-28.00	-31.4	-67.3	-76.1	-8.8
5	3.835	-20.60	-27.8	-73.6	-67.2	6.3
	5.420	-16.70	-29.4	-85.3	-70.2	15.1
	6.440	-15.60	-30.7	-89.6	-71.7	17.8
	7.360	-15.15	-32	-82.3	-72.9	9.4

TABLE 2
PHASE I MEASUREMENTS RECEIVER AT WEDGEWOOD MANOR
SPACE WAVE ANTENNA GAIN CALCULATIONS

TRANSMIT SITE	FREQ (MHz)	TX ANT GAIN (dBi)	RX ANT GAIN (dBi)	MEASURED PATH LOSS (dB)	CALCULATED FREE SPACE SPREADING LOSS (DB)	EXCESS LOSS ABOVE THE FREE SPACE LOSS (dB)
OSB	3.835	-13.2	-22.60	-98.0	-74.2	23.8
	5.420	-9.2	-23.70	-115.5	-77.2	38.3
	6.440	-8.1	-24.60	-120.0	-78.7	41.3
	7.360	-7.6	-25.50	-122.0	-79.9	42.1
6	3.835	-31.1	-18.40	-81.7	-74.2	7.5
	5.420	-33.2	-19.80	-91.7	-77.2	14.4
	6.440	-32.1	-20.80	-93.8	-78.7	15.1
	7.360	-31.6	-21.80	-97.4	-79.9	17.5
17	3.835	-10.9	-22.50	-104.5	-76.6	27.9
	5.420	-6.9	-22.90	-123.8	-79.6	44.2
	6.440	-5.7	-23.30	-126.0	-81.1	44.9
	7.360	-5.3	-23.80	-125.5	-82.3	43.2
DRJ	3.835	-31.1	-21.60	-83.0	-76.7	6.3
	5.420	-33.2	-23.30	-86.4	-79.7	6.7
	6.440	-32.1	-24.60	-91.0	-81.2	9.8
	7.360	-31.6	-26.10	-76.9	-82.4	-5.5
15	3.835	-31.1	-19.00	-70.8	-76.0	-5.1
	5.420	-33.2	-19.60	-78.3	-79.0	-0.7
	6.440	-32.1	-20.30	-73.4	-80.5	-7.0
	7.360	-31.6	-20.90	-84.2	-81.6	2.6
10	3.835	-11.5	-19.00	-100.7	-74.3	26.4
	5.420	-7.4	-20.00	-110.6	-77.3	33.3
	6.440	-6.4	-20.80	-116.6	-78.8	37.8
	7.360	-6.0	-21.60	-119.5	-79.9	39.5
11A	3.835	-14.8	-18.50	-102.2	-74.9	27.3
	5.420	-10.8	-19.00	-119.2	-77.9	41.3
	6.440	-9.7	-19.40	-111.1	-79.4	31.7
	7.360	-9.3	-19.90	-122.3	-80.6	41.7
14A	3.835	-13.0	-18.50	-95.4	-74.1	21.2
	5.420	-9.1	-19.00	-114.9	-77.1	37.7
	6.440	-8.0	-19.40	-110.5	-78.6	31.9
	7.360	-7.4	-19.90	-115.3	-79.8	35.5
14C	3.835	-12.20	-18.40	-77.9	-74.1	3.7
	5.420	-8.30	-19.30	-89.3	-77.1	12.1
	6.440	-7.10	-20.00	-81.6	-78.6	2.9
	7.360	-6.70	-20.90	-80.0	-79.8	0.2
9	3.835	-11.50	-18.00	-90.9	-71.1	19.8
	5.420	-7.50	-19.70	-107.5	-74.1	33.4
	6.440	-6.40	-19.40	-105.6	-75.6	29.9
	7.360	-6.00	-20.00	-108.1	-76.8	31.3
4	3.835	-33.50	-19.50	-96.1	-70.7	25.4
	5.420	-29.60	-20.50	-103.9	-73.7	30.2
	6.440	-28.50	-21.40	-104.1	-75.2	28.9
	7.360	-28.00	-22.30	-104.4	-76.4	28.0
5	3.835	-20.60	-19.00	-97.2	-70.8	26.4
	5.420	-16.70	-19.90	-103.7	-73.8	29.9
	6.440	-15.60	-20.60	-101.9	-75.3	26.6
	7.360	-15.15	-21.40	107.0	-76.4	30.5
12	3.835	-18.30	-24.60	-97.9	-76.9	21.0
	5.420	-13.50	-26.10	-111.2	-79.9	31.3
	6.440	-12.30	27.20	110.4	-81.4	29.1
	7.360	-11.90	-28.40	-114.4	-82.5	31.8

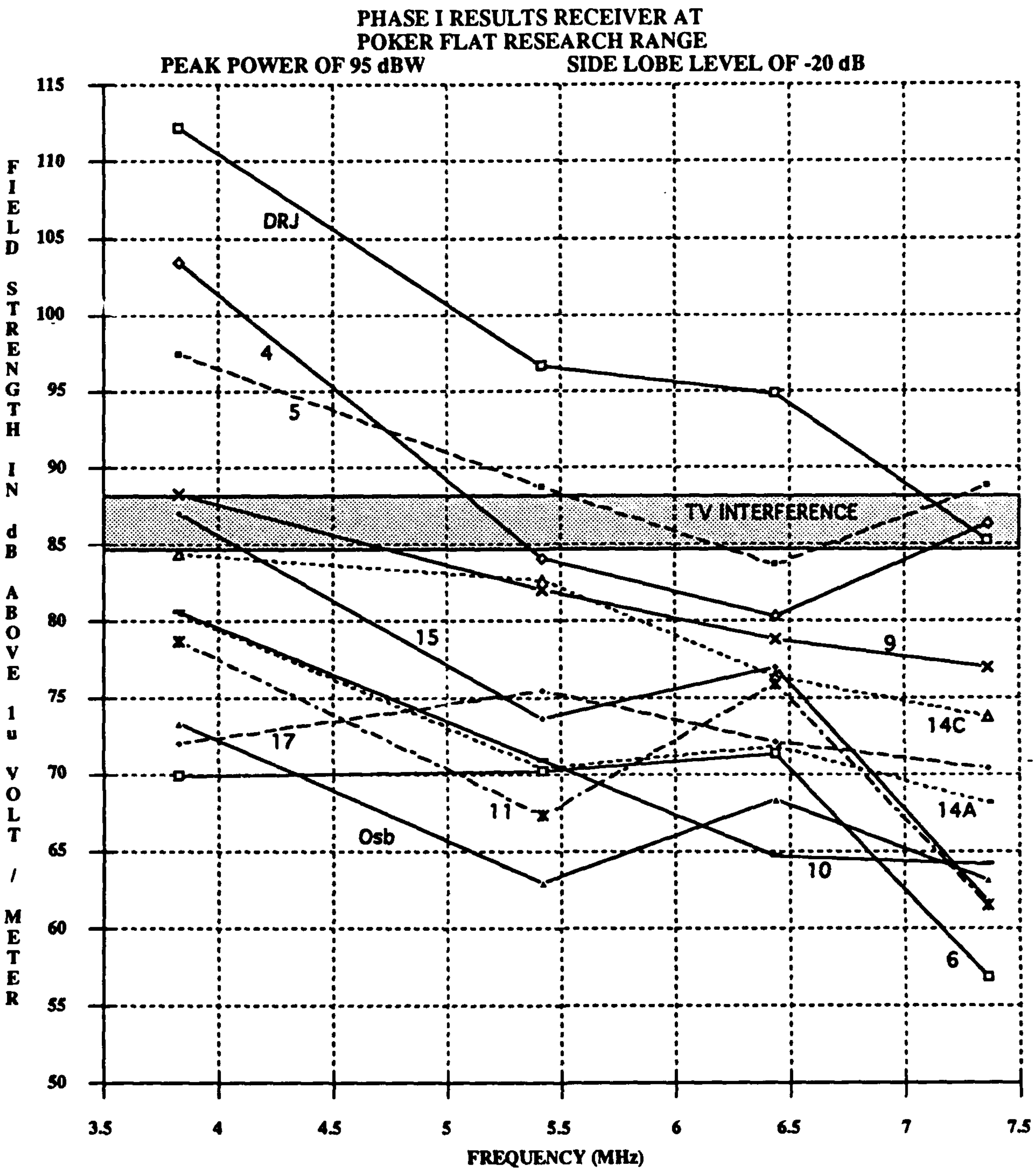

Figure 8. Phase I results with receiver at Poker Flat Research Range

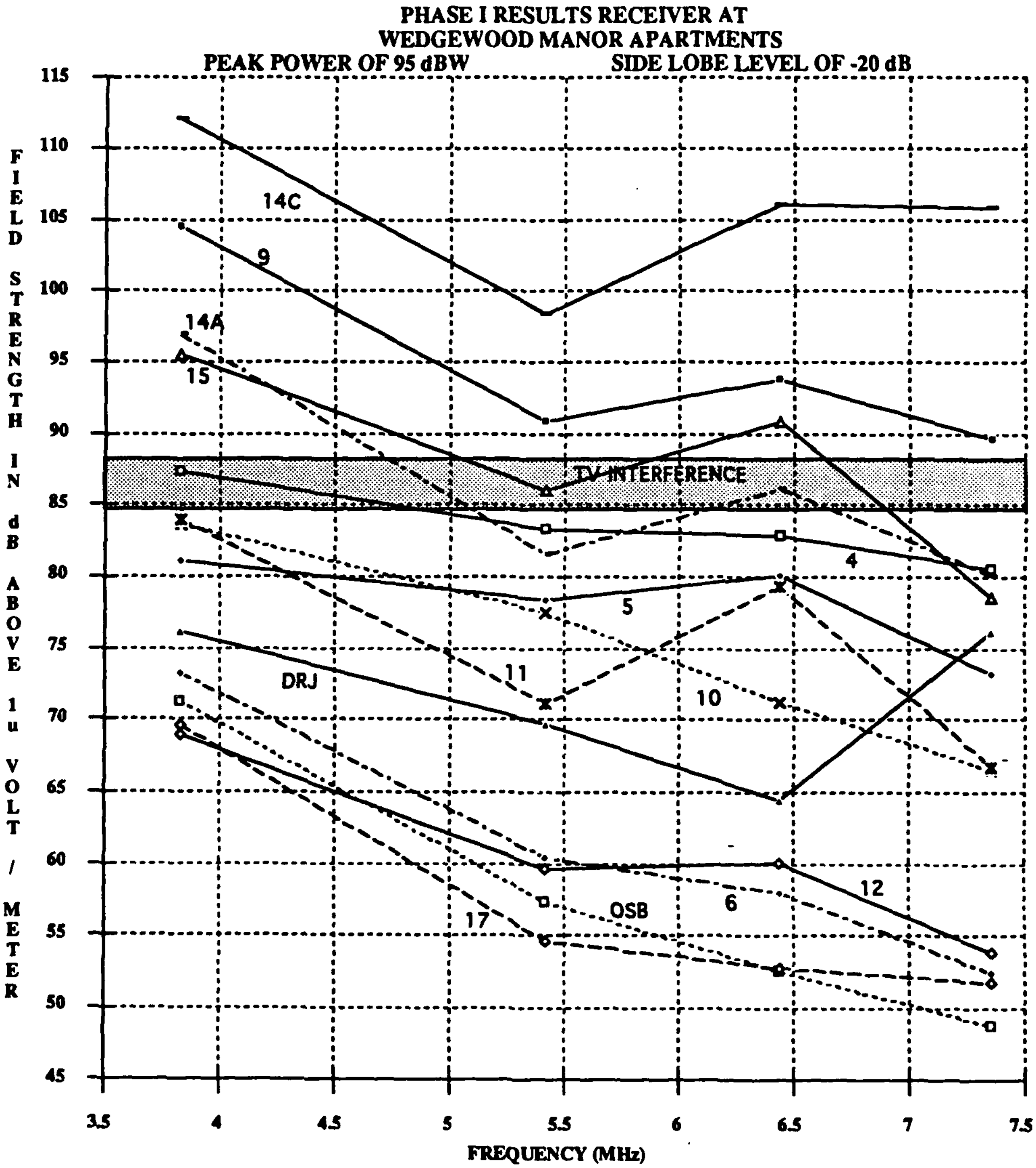

Figure 9. Phase I results with receiver at Wedgewood Manor Apartments

A major consequence of EMI would be interference to the reception of TV signals in the vicinity of the HAARP transmitter. The non-linearities in a television's receiver will transform the coupled HF energy, introducing a VHF signal that will interfere with the video display and audio output. TV receivers are generally most susceptible to interference caused by signals within the same channel ("co-channel"), and those at frequencies in the upper and lower adjacent TV channels [10]. A limited number of laboratory measurements were conducted to define the signal amplitude in the HAARP band that would produce interference to a TV video signal. Acceptable video interference is a qualitative issue, since different viewers would offer different opinions as to what is an acceptable video presentation. In addition, TV receivers produced by different manufactures would be expected to exhibit a wide range of susceptibility to HF energy coupled into the TV receiver.

In order to attempt to put some bounds on this problem, an HF signal generator was connected directly to the input of a TV receiver of standard commercial quality and the HF signal amplitude that produced video interference (as judged by the authors) was measured. Since harmonics of the HAARP frequencies would produce the distortion, the lowest portion of the TV band would be the most affected. Therefore, the direct HF signal injection was performed with the TV tuned to channels 2 and 3. The results of the limited measurements demonstrated that an HF signal in the range of -54 to -60 dBW resulted in video interference. Using (8) to convert these numbers to field strength amplitudes produced values of 64.7 to 68.2 dB relative to 1 μVolt/meter. These data were obtained using direct signal injection into a TV receiver. The HAARP energy will be delivered to a TV receiver via the TV's antenna and antenna transmission line. In order to estimate the mismatch loss at HAARP frequencies for a TV antenna, the transfer function for a "rabbit ear" antenna was measured. The rabbit ear provides approximately 20 dB loss in the HAARP band. The TV interference levels have been scaled by the 20 dB mismatch loss and are shown as shaded areas in Fig. 8 and 9. Most of the transmitter locations would produce signal amplitudes below these TV interference levels for the receiver at either the PFRR or the WMA location. But several potential HAARP transmitter locations would be rejected by this TV interference criteria.

D. Phase II - Results

The two potential transmitter sites selected for more comprehensive measurements were Sites #17 and #12. The Phase I data for Site #6 and the OSB site were comparable to the results for Site #17 and #12. The #6 and OSB locations were not selected for Phase II measurements because the propagation path from these two locations was a direct line-of-sight path to active mining operations. For Site #17, measurements were performed at seven receiving locations. The Site #17 receiving locations are shown in Fig. 10. For Site #12, six receiving locations were established and are shown in Fig. 11. Fig. 12 shows field strength data for a transmitter at Site #17. Numbers are relative to 1 μVolt/meter for a 95 dBW transmitter, with sidelobe levels at -20 dB relative to the peak. For the Site #12 candidate location, the field strength data is shown in Fig. 13 for the same transmitter power specifications.

The measured field strength values in Figs. 12 and 13 do not monotonically decrease with increasing frequency for a given receiving site, which was also seen in the Phase I data. From the free space path loss, the plane wave field strength values would decrease by 8.8 dB from 2.84 to 7.83 MHz. While the data for the transmitter at Site #17 (Fig. 12) does not display as much variation as the Phase I data, the deviation from plane wave propagation is quite apparent. An example is the data for Cleary Summit, which is a nearly straight line propagation path but shows a spread of over 3.5 dB from the highest to the lowest field strength amplitude. Most of the other data in Fig. 12 also diverge from plane wave propagation to some degree. The data for the transmitter at Site #12 (Fig. 13) shows more departure from plane wave propagation than is seen in from Site #17. The Eielson Air Force Base (EAFB) data shows the largest spread, a change of 22.1 dB between 5.69 and 7.83 MHz.

The data in Figs. 12 and 13 support the conclusion reached for the Phase I data that the propagation from the transmitter to the receiver is dominated by scattering and does not conform to simple free space, plane wave propagation. As further evidence, the College Digisonde data was examined and established that the ionospheric conditions precluded skywave reception for the HAARP frequencies for the case of the

transmitter at Site #17. In addition, the Digisonde data revealed that spread-F conditions existed for the data that was collected with the receiver at EAFB and Fort Wainwright (FW), with the transmitter at Site #12. Spread-F conditions are characterized by a large amount of dispersion, which results in enhanced signal attenuation. The curves in Fig. 12 are fairly flat in comparison to those in Fig. 13. The widest deviation from monotonically decreasing data is that for EAFB in Fig. 13, when spread-F was present. Therefore, skywave propagation did not contribute to these field strength measurements. The shape of the curves in Figs. 12 and 13 is most probably the result of scattering and/or multipath.

Fig. 12 shows that for the transmitter at Site #17, a level of EMI sufficient to produce video interference would be expected at about half of the receiver locations examined for this report. Fig. 13 shows that the video interference would exist at only 2 or 3 of the receiver locations. However the Haystack location is one of those expected to be in the interference region and the Haystack location is an area where a subdivision for homes appears on local maps.

In addition to TV interference, it is necessary to examine the radiation hazard to electro-explosive devices (EED) and to personnel. A computer program to calculate these hazards was obtained [11]. The EED hazard would exist only at the PFRR and the computer hazard calculations established that all of the potential HAARP transmitter locations satisfy the EED hazard criteria. The personnel hazard would only exist relatively close to the transmitter (on the order of tens of meters) and is therefore considered to be no worse than any other high power RF installation.

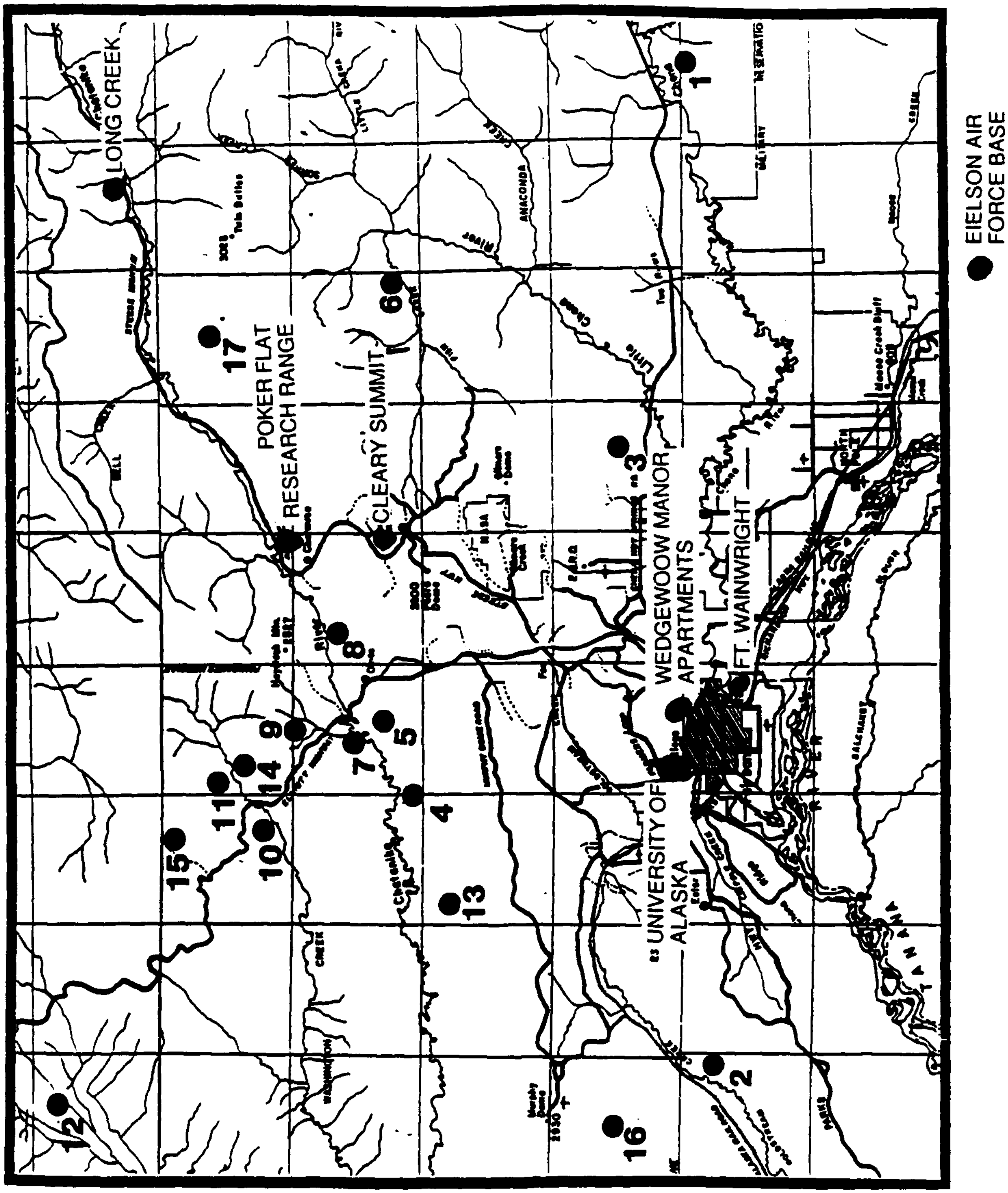

Figure 10. Transmitter at ROEN Site #17 and the seven receiver locations.

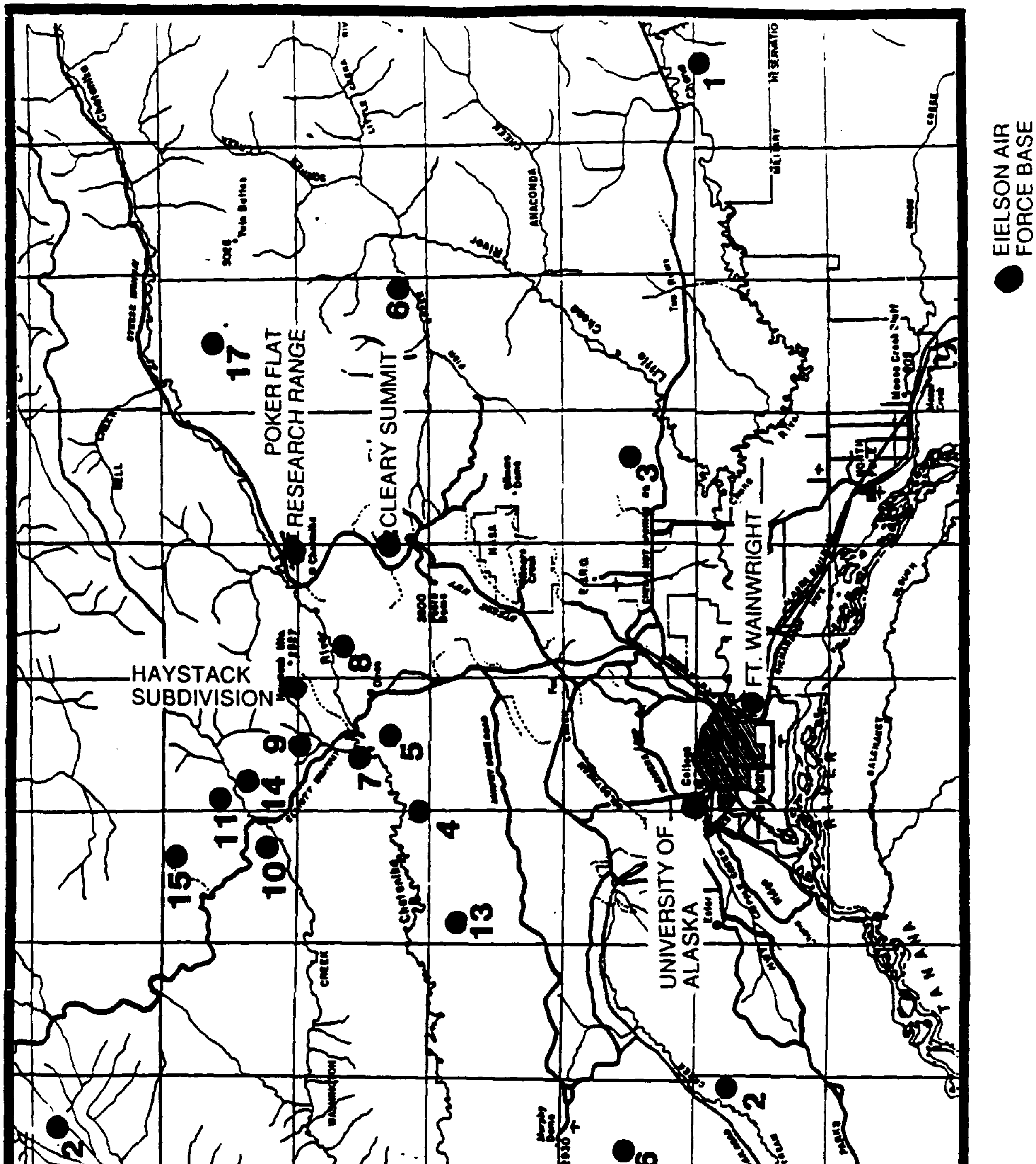

Figure 11. Transmitter at ROEN Site #12 and the six receiver locations.

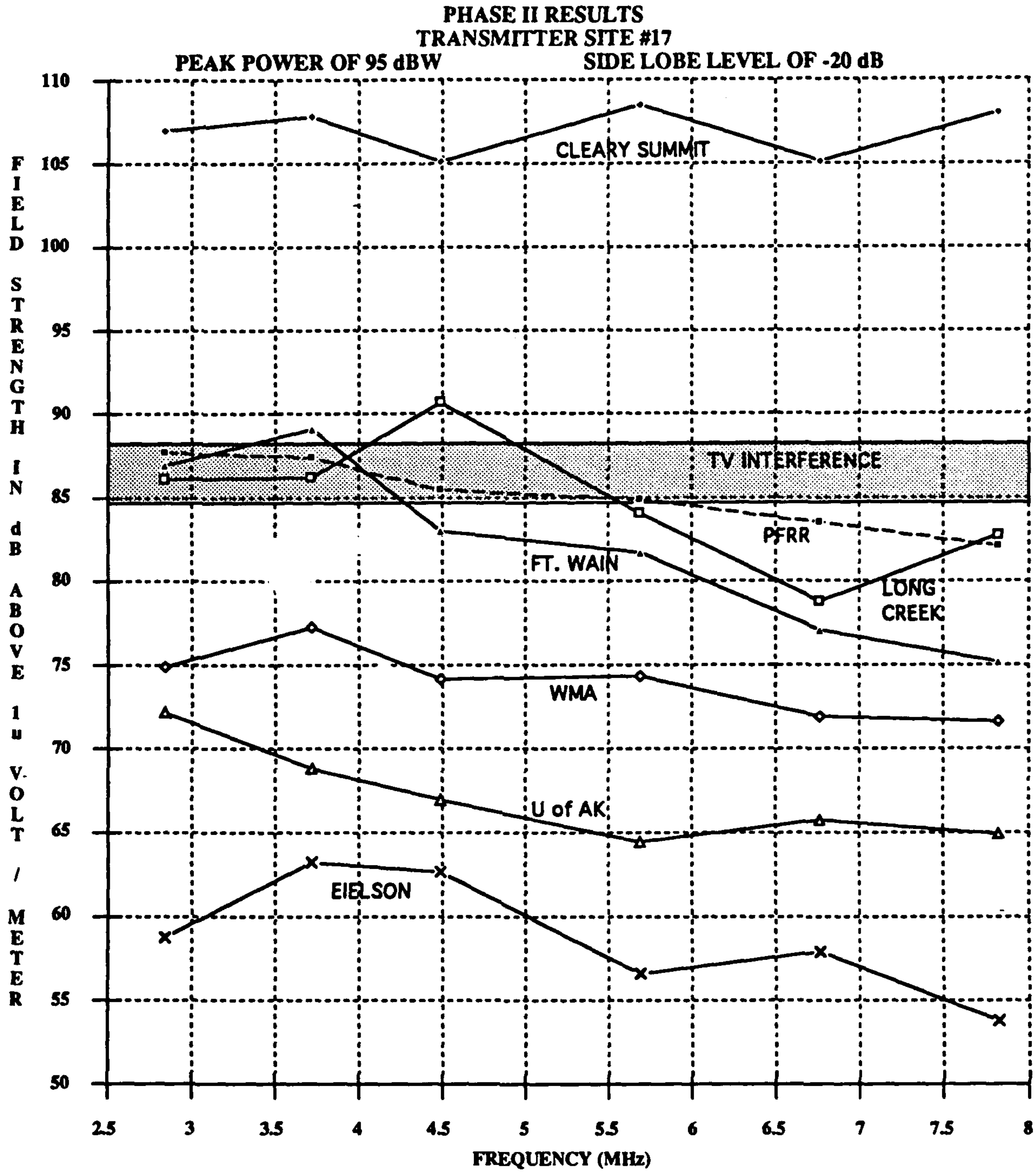

Figure 12. Phase II results with transmitter at Site # 17

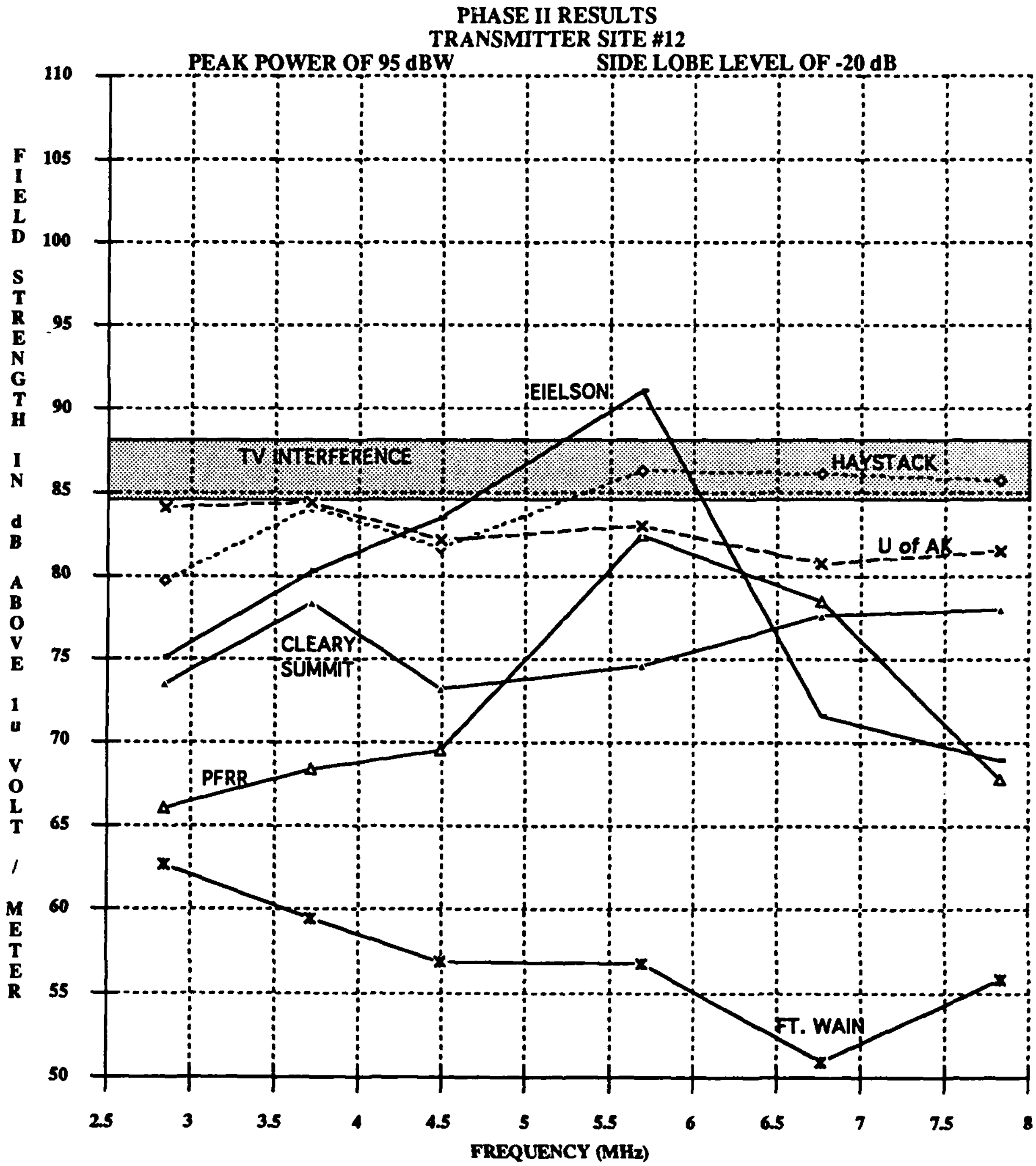

Figure 13. Phase II results with transmitter at Site # 12

IV. Conclusions

The potential for EMI resulting from the installation of the HAARP high power HF transmitting facility in the vicinity of Fairbanks, Alaska has been examined for a number of candidate sites. The EMI field strength values have been determined using the HAARP transmitter specifications. The measurements were conducted in two phases. Phase I of the measurements surveyed 13 candidate transmitter locations to determine the electromagnetic impact of HAARP and to select two primary potential installation sites for the comprehensive examinations conducted during Phase II. Two receiver locations were chosen for the Phase I survey, one site to represent the residential community of Fairbanks and the other to assess the impact on the Poker Flat Research Range.

The Phase I received signal amplitudes were compared to free space, plane wave propagation conditions. The propagation paths for the majority of cases could not be characterized as free space, line-of-sight, plane Earth, or curved Earth but rather a combination of multi-path and scattering paths caused by the rugged topography of the region resulting in a non-predictable attenuation characteristic as a function of distance from the transmitter site. The data analysis showed that the measured signal attenuation was greater than the plane wave attenuation by as much as 53 dB.

The preliminary analysis of the Phase I data showed that the candidate transmitter locations with the best overall EMI and geographical characteristics were the Roen sites #17 and #12. To examine the EMI impact from site #17 and #12, *temporary transmitters* were installed at those two locations. Received signal amplitudes were measured at seven locations representing the major population centers and other commercial and public facilities in the vicinity of Fairbanks.

The radiation field from a HAARP antenna array was examined to determine if a hazard would exist for electro-explosive devices or to personnel. Using the HAARP transmitter specifications for the input to a computer calculation showed that all potential HAARP transmitter locations would not present any hazard for electro-explosive devices. The personnel hazard form HAARP would exist only relatively close to the transmitter, on the order of tens of meters, and would not be any

worse than any other high power RF installation.

Another potential EMI impact from a HAARP transmitter would be to produce TV video interference. The measured field strengths for the Phase I data showed that approximately 35% of the candidate transmitter locations would produce TV video interference. The Phase II data showed that TV video interference would be produced at some of the sampled receiver locations for both the site #17 and #12 candidate HAARP transmitter locations. In particular, the site #17 transmitter would produce severe TV video interference in the Cleary Summit area. Distortion would also be produced at the Lone Creek subdivision, the Poker Flat Research Range and at Ft. Wainwright. The Site #12 transmitter location would produce distortion in the Haystack subdivision and at Eielson Air Force Base.

Since HAARP operates in the HF band, the possibility that skywave reflections could have contributed to the measured field strengths presented in this report was investigated. Data from the Digisonde that is operated in the vicinity of Fairbanks showed that during both the Phase I and Phase II measurements ionospheric conditions precluded the reception of skywave energy at the receiver locations. Consequently, we believe that the data presented in this report are the result of terrestrially propagated energy. The primary mission for HAARP is to radiate energy in the direction of the overhead ionosphere. During actual HAARP operations, skywave propagation to a receiver location is possible and may add to any ground wave energy that is present. Since skywave propagation is a consequence of ionosphere physics, the possibility will always exist for skywave reflection of energy.

V. Acknowledgments

The authors are indebted to the assistance provide by Frank Sullivan, John Bashista and Ed Barr, of NRL during the measurement operations. Their diligent efforts and dedication to job performance enabled completion of the measurements, in less than ideal circumstances. The cooperation of the personnel at the NOAA Gilmore Tracking Station aided the measurement preparation phase of this effort. The support of the personnel at the Poker Flat Research Range and at the Geophysical Institute, University of Alaska also contributed to the success of this task. The cooperation of the Alyeska Pipeline Service Co. also provided assistance with VHF/UHF communications in a difficult radio environment.

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